Parachute Deployment

Dean F. Wolf

Parachute Seminar

3rd International Planetary Probe Workshop

Introduction

- **Methods of Deployment**
- **Deployment Bags**
- **Pilot parachutes**

Importance

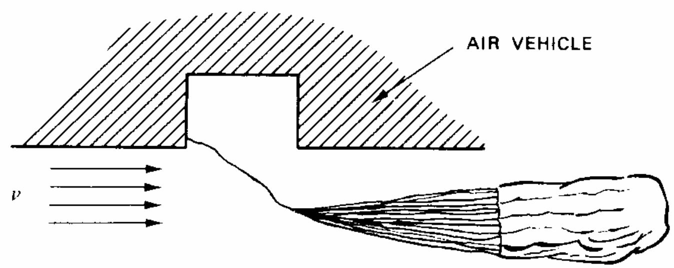
- **“The best designed parachute will not operate reliably if it is not deployed properly”**
- **“Proper deployment of the parachute is at least half of the battle in parachute system design”**
- **“Deployment considerations dominate the design of any large parachute”**

Parachute Deployment

- **Denotes a sequence of events that begins with the opening of a compartment or pack attached to the body to be recovered**

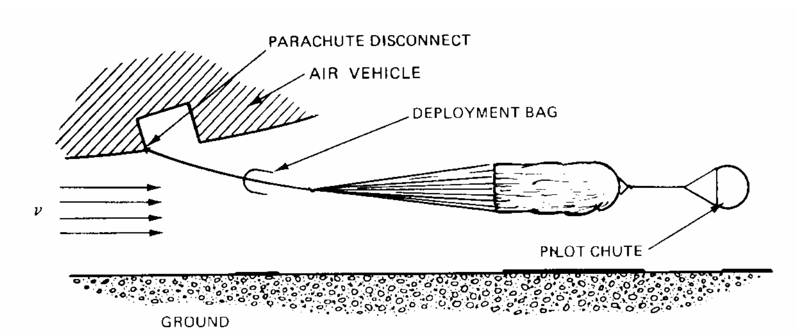
- **Continues with the extraction of the parachute until the undamaged canopy and suspension lines are stretched behind the body and the parachute is ready to start the inflation process**
  - Two types of deployment
    - Lines first deployment
    - Canopy first deployment
- **Need for controlled deployment increases with the parachute size and deployment velocity**

Uncontrolled Deployment



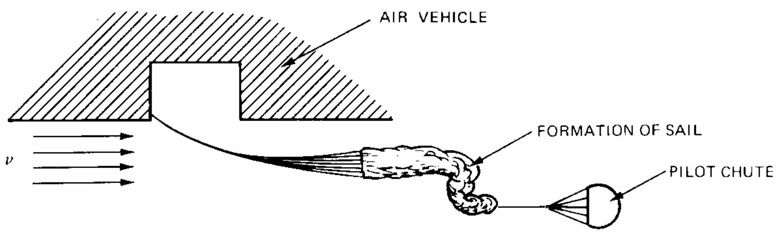
- Knacke NWC TP 6575 Figure 6-1
- Usually a canopy first deployment
- Partial canopy inflation at line stretch
- Very large snatch load
- Except at very low speeds, a guaranteed disaster

Canopy First Deployment



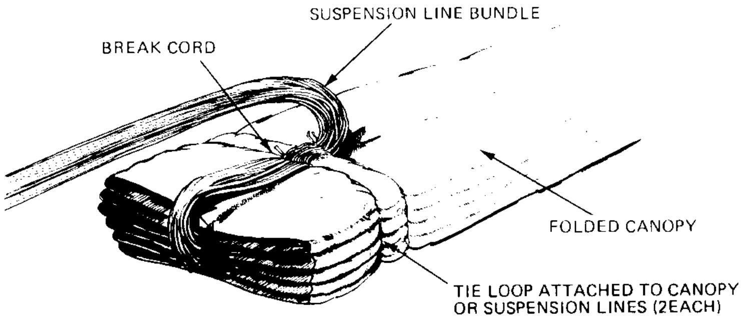
- Knacke NWC TP 6575 Figure 6-5
- B-47 landing chute
- Undesirable method of deployment
  – Sometimes necessary
- Large snatch loads
  – Canopy acts as "lumped mass"
- Snatch load usually greater than inflation loads

Canopy First Deployment



- Knacke NWC TP 6575 Figure 6-2
- Exposed canopy can also cause canopy sail
- Possible entanglement
- Possible friction burning

Skirt Hesitator

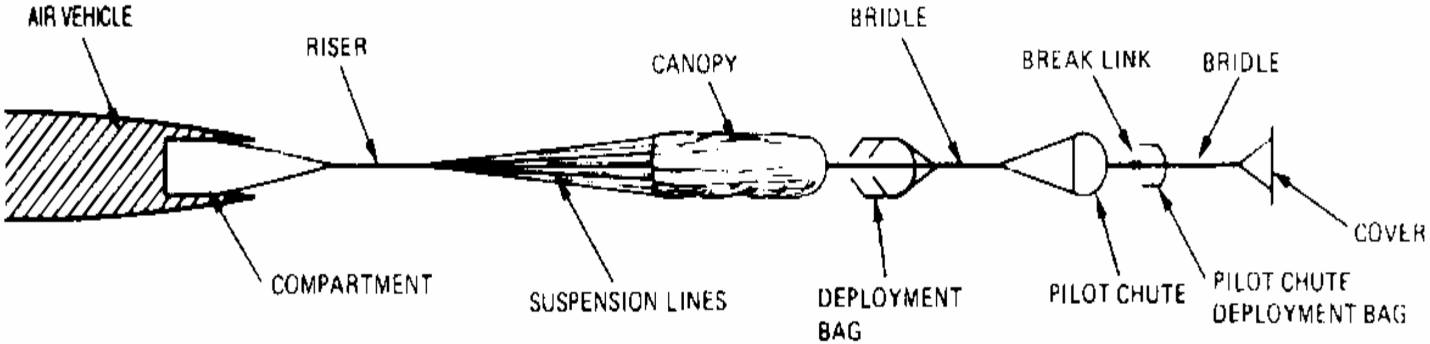


- **Knacke NWC TP 6575 Figure 6-39**
- **Canopy first deployment requires skirt hesitator or equivalent**
- **Skirt hesitator keeps canopy from inflating during deployment**
  - **Any inflation increases snatch load**

Benefits of Lines First Deployment

- **Minimizes the parachute snatch force by incrementally accelerating the suspension lines and canopy to vehicle speed**
- **Entanglements, line-overs, canopy inversions, and canopy damage are prevented by keeping tension on all parts of the deploying parachute**
- **Inflation time and force scatter are minimized**
- **Assists in uniform deployment (and inflation) of parachute clusters**

Lines First Deployment Concept Incremental Acceleration of Parachute System Elements



Pilot Chute Deployment

- Small angle of attack at deployment
- Multiple pilot parachutes
- No line sail

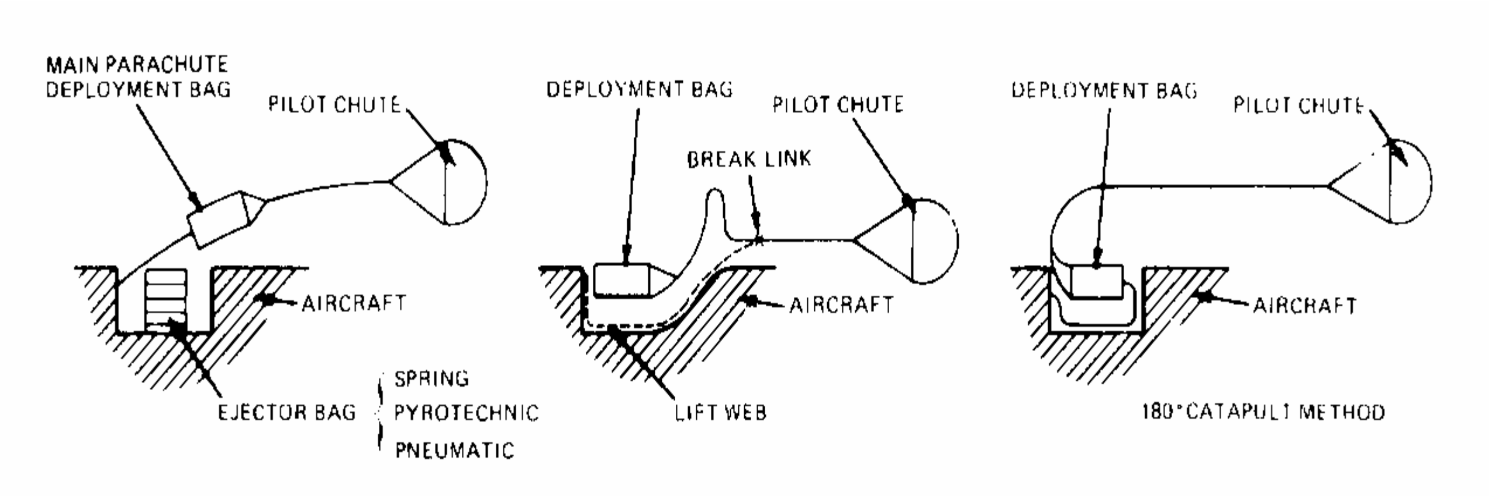
Down-wind and Cross-wind Parachute Deployments

- **Ideally, parachute deployment should be made down-wind**
  - Payload at zero angle of attack

- **Cross-wind deployments**
  - Less reliable
  - Complicates deployment bag ejection
  - Causes line sail
  - Causes skirt inversions
  - In-folding at skirt can prevent inflation

Cross Wind Bag Ejection Methods

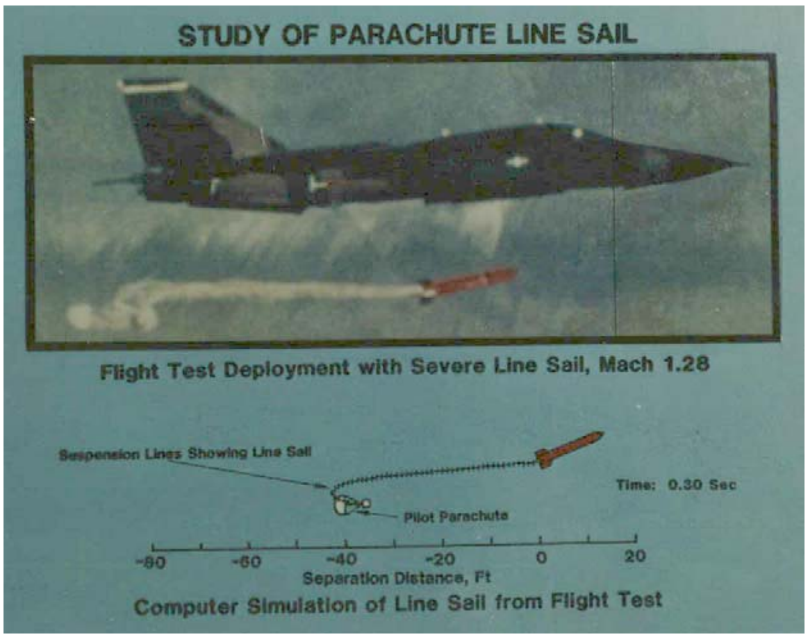
Knacke NWC TP 6575 Figure 6-10



Parachute Line Sail

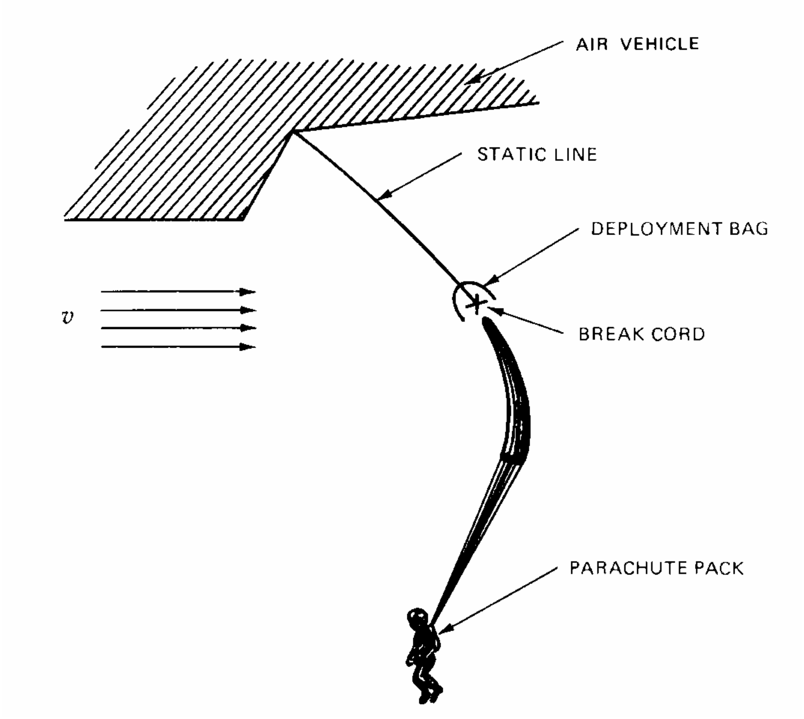
- **Line sail occurs when the aerodynamic force on the risers and suspension lines causes premature stripping of the suspension lines from the deployment bag**
  - Cross-wind deployment
  - Inadequate drag from the pilot parachute
  - Inadequate line tie strength
  - Heavy metal fittings or load cells

Bomb Parachute Line Sail



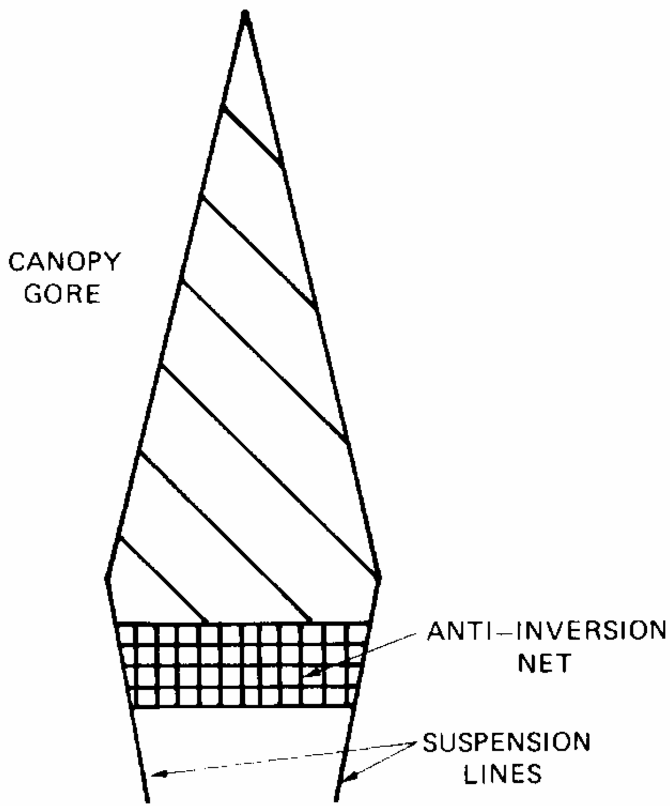
- **Inadequate pilot parachute drag**
- **Single pilot parachute did not inflate completely in transonic wake**
- **Fix was cluster of pilot parachutes**

Parachute Static Line Deployment in Cross Flow



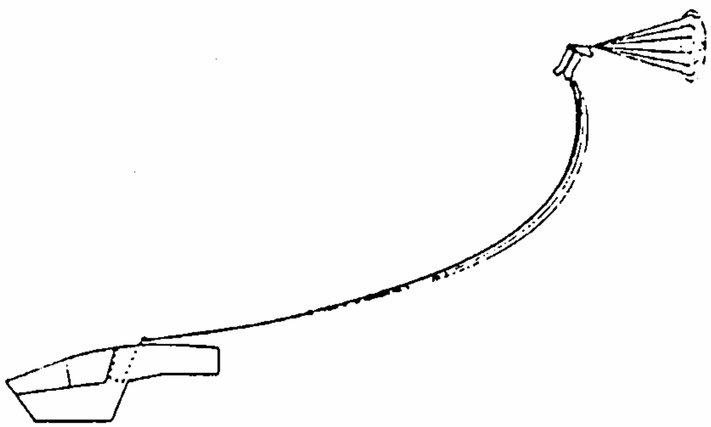
- Knacke NWC TP 6575 Figure 6-3
- Airdrop side door exit
- Caused skirt inversions
  - "Mae West"

Parachute Static Line Deployment in Cross Flow



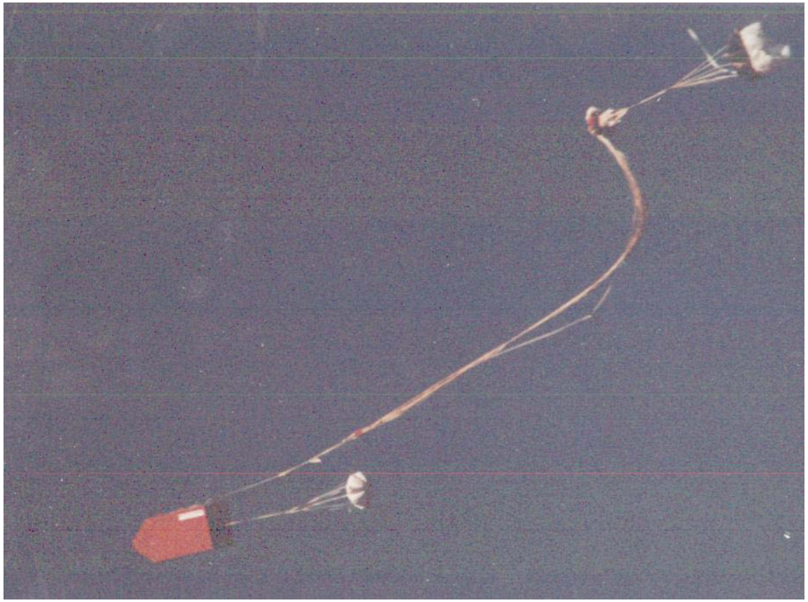
- Knacke NWC TP 6575 Figure 6-33
- Design fix for skirt inversions
- Anti-inversion net added below skirt

F-111 Crew Escape Module Parachute Deployment



- **Cross flow deployment required**

F-111 Crew Escape Module Parachute Deployment



- **Design for line sail**
- **Protect canopy from adverse deployment**

Parachute Line Sail (Continued)

- **During line sail …**
  - Suspension lines and canopy can be damaged from the friction between components
  - Deployment bag can rotate – not be aligned with the airflow
  - Unequal loading of suspension lines during the snatch force generated at line stretch
- **Results**
  - Vary between minor damage and catastrophic failure

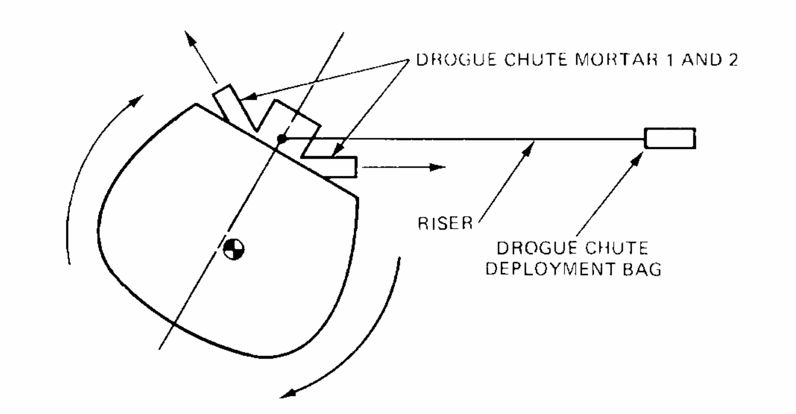
Deployment Initiation

- **Pilot parachute**
  - Cover plate
    - Forced ejection
    - Aerodynamic forces
  - Drogue gun
  - Mortar
  - Telescoping tubes
  - Springs

Deployment of Main Parachute

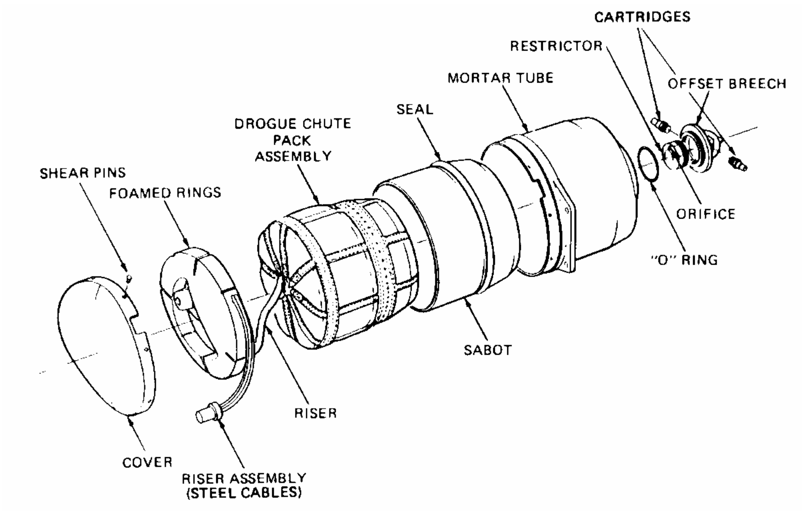
- **Initial velocity high, deployment bag coasts to canopy stretch**
  - Mortar
  - Telescoping tubes
- **Initial velocity low, deployment bag continues to accelerate to canopy stretch**
  - Pilot parachute
  - Tractor (extractor) rocket

Apollo Mortar Deployed Drogue Chutes



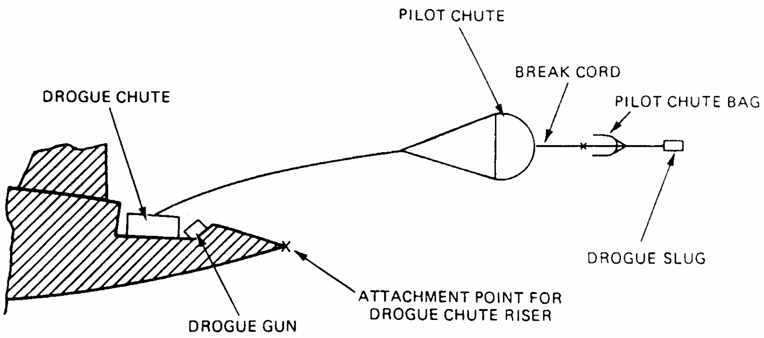
- Knacke NWC TP 6575 Figure 6-7
- Mortars fired from tumbling command module
- Dual mortars used for reliability

Apollo Drogue Chute Mortar Assembly



- Knacke NWC TP 6575 Figure 6-8
- Steel cable risers required because of possible contact with command module
- Manned vehicle
  - Low reaction loads

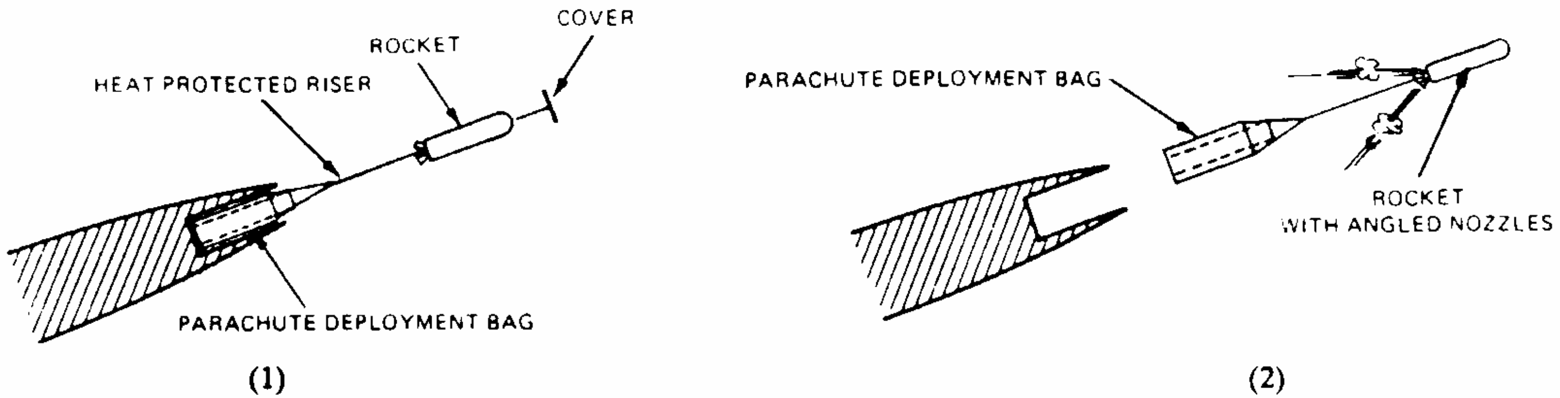
Drogue Gun Pilot Deployment



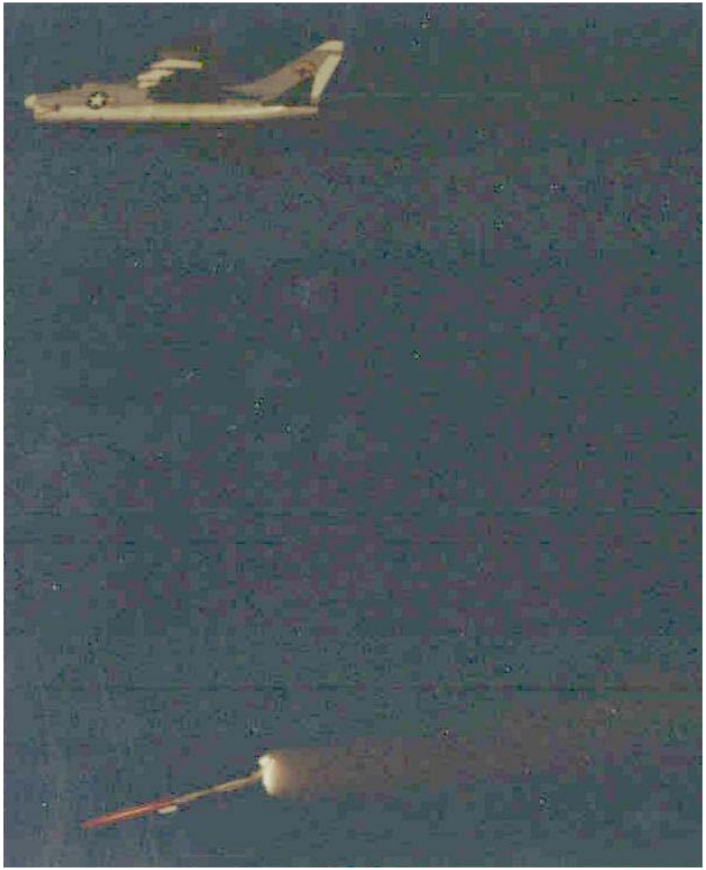
- **Knacke NWC TP 6575 Figure 6-6**
- **Drogue gun fires metal slug**
- **Inertia of slug pulls pilot bag off of parachute**

Tractor Rocket Deployment

Knacke NWC TP 6575 Figure 6-9



Tractor Rocket Deployment



- **Tractor rocket has longer action distance than mortar**
  - **Smaller deployment bag acceleration**
- **Less deployment bag dynamics than mortar**

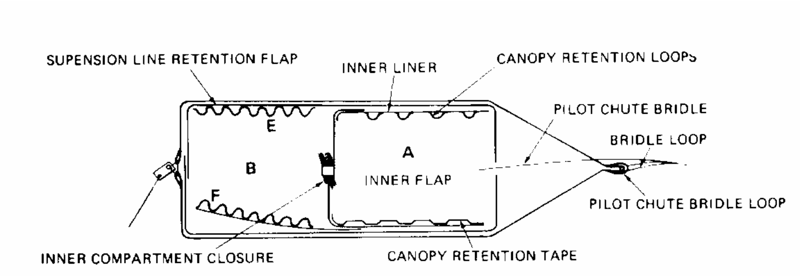
Parachute Deployment Components

- **Parachute deployment sequence**
  - Riser
  - Suspension lines
  - Canopy
- **Deployment bags are the best methods of ensuring this sequence**
- **Other methods**
  - Deployment sleeves
  - Skirt hesitator
  - Sacrificial panel
  - Quarter bag

Deployment Bag Design

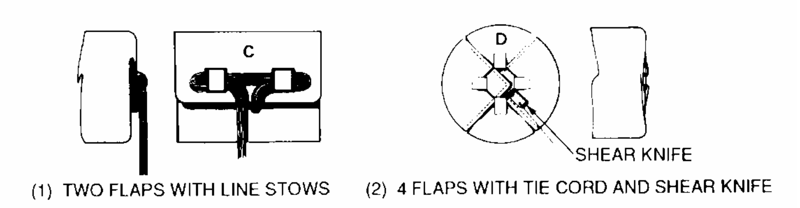
- **Flexible textile container**
- **Optimum shape**
  - Cylinder with L/D of 2 to 4
  - Must fit vehicle
- **Irregular shape**
  - Difficult to pack with high density
  - Usually requires pressure packing
  - Sometimes requires autoclaving
- **Separate compartments**
  - Canopy
  - Suspension lines
  - Risers

Typical Deployment Bag



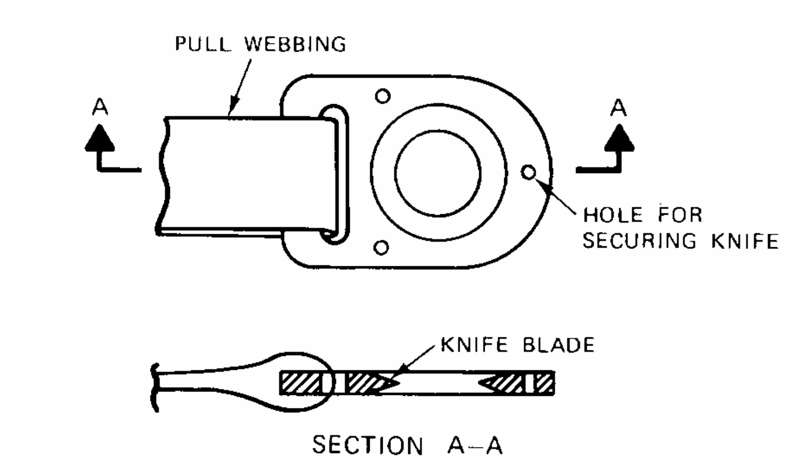
- Knacke NWC TP 6575 Figure 6-34
- Separate compartments for canopy and lines
- Compartments open at correct time

Typical Bag Closures



- Knacke NWC TP 6575 Figure 6-34
- Stow loops or cut loop closures
- Cut loop closures more common on high performance systems

Circular Cut Knife

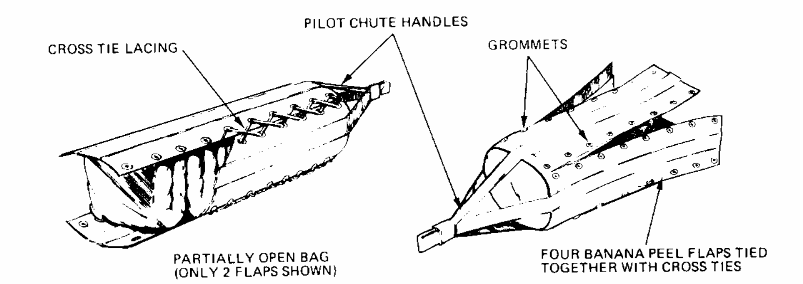


- **Knacke NWC TP 6575 Figure 6-35**
- **Closure loop passes through cut knife**
- **Lanyard pulls knife at correct time during deployment**

Retainer Loop and Cut Knives

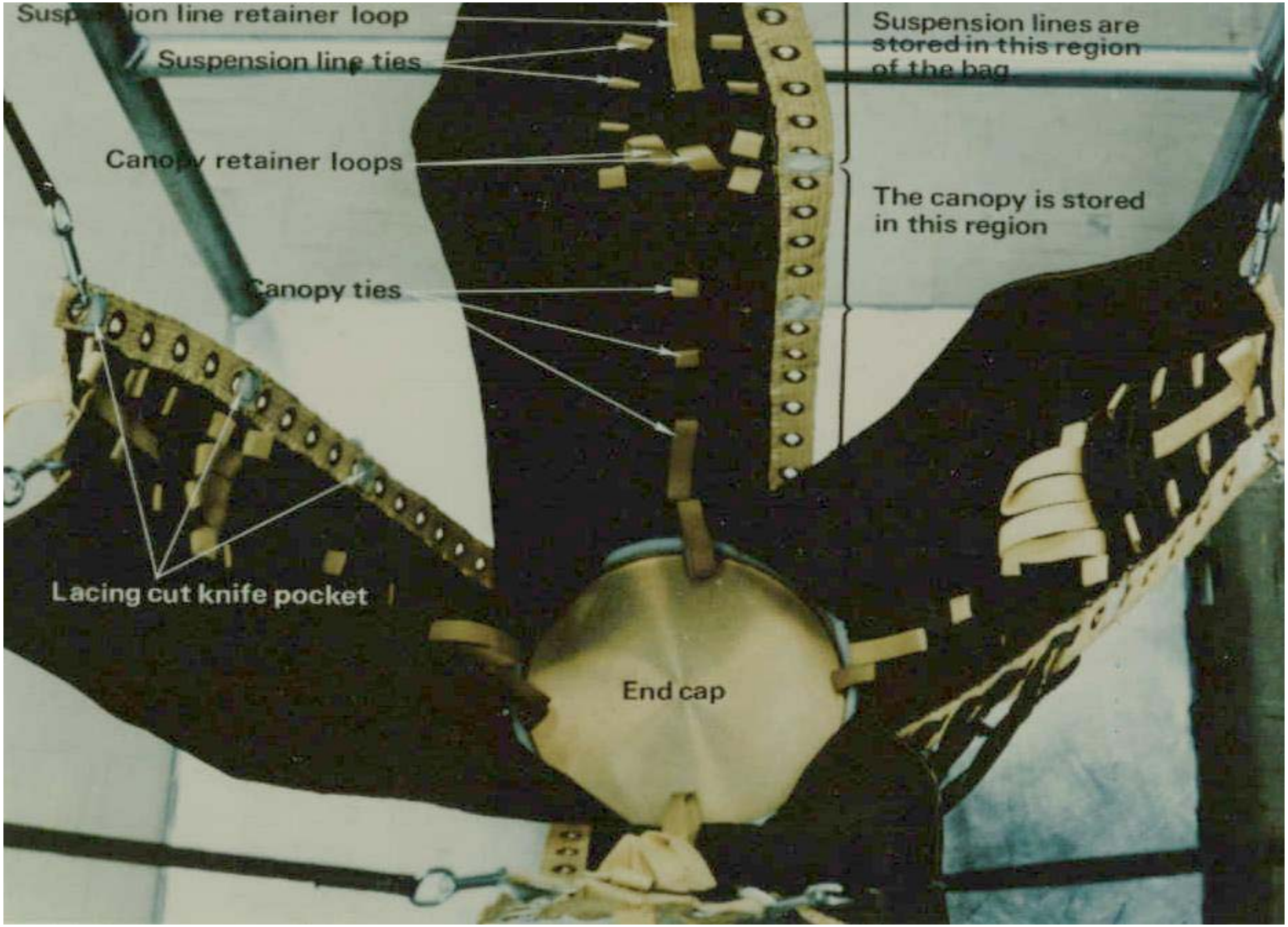
- Redundant cut knives are often used for reliability
- Closure loop can be extracted with a separate lanyard after being cut

Banana Peel Bag



- Knacke NWC TP 6575 Figure 6-36
- Large L/D pack shape deployed at high speed
- Multiple lacing cuts during deployment

Inside Banana Peel Bag



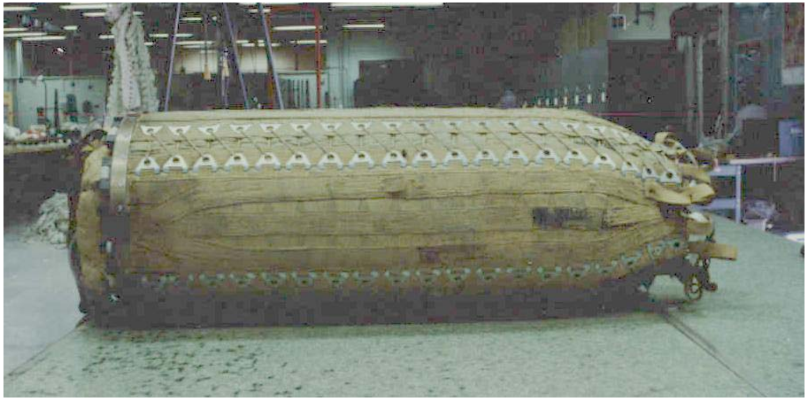
Packing Banana Peel Bag

- **Before lacing shape is rough**

Packing Banana Peel Bag

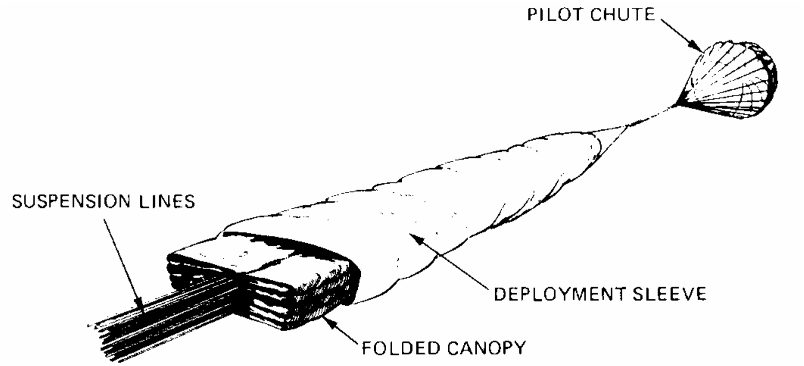
- **Lacings are tightened using a pneumatic lacing machine**
- **Manual labor and skill are also required**

Packing Banana Peel Bag



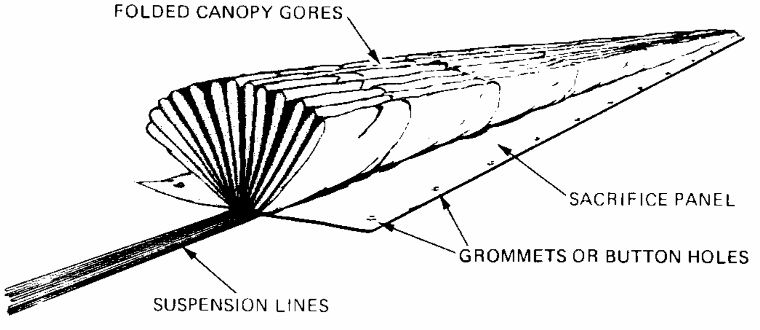
- Very precise final shapes are possible
- High densities of 50 lb/ft^3 or more are achievable

Deployment Sleeve



- Knacke NWC TP 6575 Figure 6-37
- “Poor mans” deployment bag
- Mostly used for low speed deployments of low density packs

Sacrifice Panel



- Knacke NWC TP 6575 Figure 6-38
- Wraps around canopy and provides some protection during deployment
- Does not protect against internal friction

Pilot Parachutes

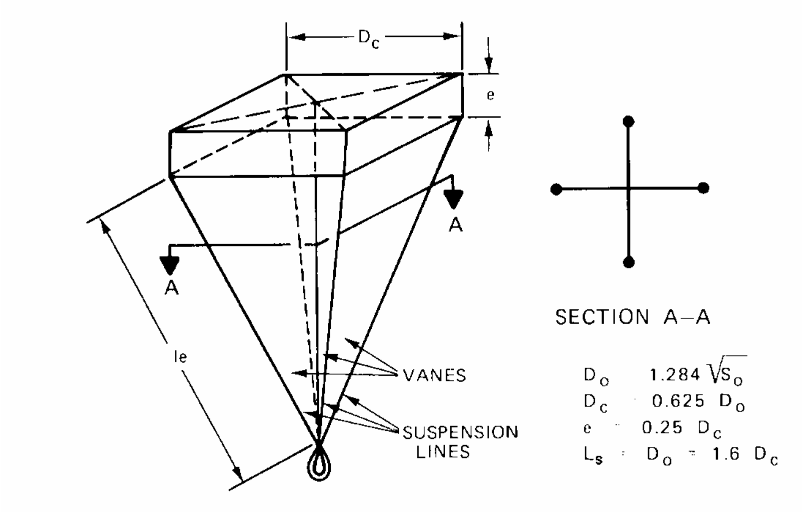
- **Pilot parachutes are used to deploy larger parachutes from their storate containers into good airflow behind the payload**

- **Requirements**
  - Inflate reliably and quickly
  - Must be stable and develop the predicted drag
    - Influences repeatable trajectory

Other Requirements

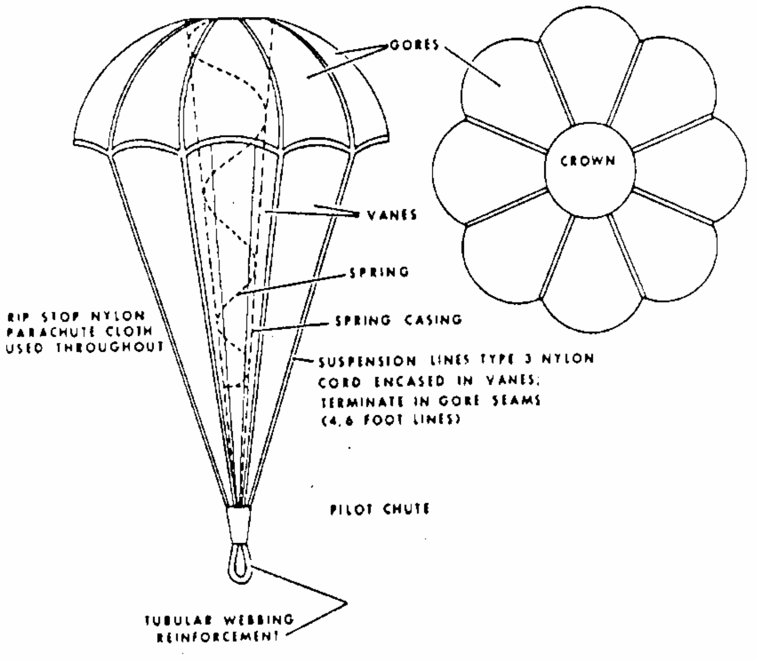
- **Main parachute pack acceleration considerations**
  - 4 to 5 g's minimum
- **Main parachute pack relative velocity considerations**
  - **High bag strip velocities cause friction burning and other causes of damage**
- **Cross-wind deployments**
  - Increase minimum velocity accelerations
- **Variable pilot parachute drag area**

Box Type Pilot Chute



- Knacke NWC TP 6575 Figure 6-32
- Simple construction
- Internal vanes make it very difficult to invert

Vane Type Pilot Chute



- **Internal vanes make it very difficult to invert**
- **Used with or without internal spring**

Mesh Type Pilot Chute

- **Mesh suspension lines make it very difficult to invert**
- **Reinforced radials and suspension lines for heavy duty use**

Mesh Type Pilot Chute

- **Pull down centerline for rapid inflation**

Toy Mesh Type Chute

- **Impossible to tangle up**
- **Works every time**

Pilot and Main Chute Drag Area Ratios

Knacke NWC TP 6575 Table 6-5

Deployment velocity, KEAS	Pilot-to-main-parachute drag-area ratio
< 150	0.03
150 to 250	0.02
> 250	0.005

Pilot Chute Drag Coefficients and Opening Shock Coefficients

Knacke NWC TP 6575 Table 6-6

Pilot chute type	Drag coefficient, C_{D_O}	Opening-force coefficient, C_X
Circular vane spring	0.55	2.05
Square box	0.60	2.0
Ribbon, conical	0.52	1.3[a]
Ringslot	0.60	1.4[a]
Guide surface, ribless	0.42	2.0[a]

[a] For normal applications, use C_X coefficients in Tables 5-1 and 5-2.

Parachute Deployment

Parachute Deployment

Parachute Deployment